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United States
Environmental Protection
Agency

Municipal Environmental Research
Laboratory
Cincinnati OH 45268

Research and Development

EPA-600/S2-81-029 Apr. 1981

EPA

Project Summary

Removal of Nitrate from Contaminated Water Supplies for Public Use

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The general applicability of three treatment processes for removal of nitrate from public water supplies are evaluated: reverse osmosis (RO), ion exchange, and the combination of RO followed by ion exchange. The evaluation consists of using laboratory size and field-test equipment to establish design criteria and operating experience useful for designing a full-scale plant of approximately 1 mgd capacity.

Ion exchange column tests were conducted with five strong-base anion exchange resins on nitrate-laden waters of various anion compositions. From this work, estimates of product water quality and the bed volume capacity for feedwater of any composition can be made. Also, a working hypothesis was developed from an analysis of the data about how the chemical structure of resins can be practically altered to obtain nitrate selectivity.

A 20-inch diameter pilot anion exchange column containing 4.36 cu. feet of resin, was designed and operated for over 1 year. Data from this column operation are used to verify estimates of pilot column performance and to project the cost for equipment and regenerant for a well site installation to treat up to 1 mgd. Because of the interim nature of this report, only preliminary data are reported on the operation of a 20,000-gallon per day RO system.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Three treatment processes were objectively evaluated for removing nitrate from public water supplies: reverse osmosis (RO), ion exchange, and RO followed by ion exchange. Both laboratory and field equipment were used to establish design criteria and operating experience useful for designing full-scale plants of approximately 3,800 m/day (1-mgd) capacity.

Work emphasizing the ion exchange process was done during the period July 1978 to April 1980, and work is continuing on ion exchange and RO. The remainder of the project will be discussed in the final report under this grant. Note that ion exchange experiments are being continued under this program and could alter conclusions reported here concerning the cost of the ion exchange process.

Methods and Materials

All tests were conducted at a well site (No. 3) owned and operated by the McFarland Mutual Water Company in McFarland, California. Nitrate-nitrogen levels for this water were 16 to 23

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mg/L, well above the 10-mg/L maximum contaminant level. Sulfate levels were greater than 300 mg/L.

Site improvements were designed for well No. 3 to accommodate equipment for conducting both field and laboratory-scale experiments. Water was supplied directly to a concrete pad and trailer from an existing surge tank. All product and wastewaters were discharged from the pad directly into the city sewer system. The 9.1- x 9.8- m (30- x 32-ft) pad was large enough to accommodate a field test ion exchange system, a field test RO system, and a single module RO system with the necessary tanks for temporary water storage. A trailer adjacent to the pad housed a field office and limited laboratory facilities.

A source of well No. 3 water was available in the trailer for experimental tests on various ion exchange resins in 5.1- cm (2-in.) diameter columns. Synthetic mixtures were prepared and pumped directly at measured flow rates through the ion exchange columns. Five ion exchange resins were selected for study with the 5.1- cm (2-in.) laboratory-size ion exchange columns. The selection was based on previous work, which tested 32 commercially available anion exchange resins for application of both single-bed and two-bed processes. Because only the single-bed process was chosen for this study, tests were limited to strong-base anion exchange resins. The previous study and discussions with resine manufacturers indicated that none of the resins would exhibit exceptional selectivity for nitrate ion over other major anions.

A Culligan HI-FLO 5 Water Softener Model 150* was installed and operated on the pad at well No. 3. The completely automatic water softener was converted to a semiautomatic anion exchanger by installing an industrial timer and anion exchange resin (Duolite A-101D).

Conclusions

Engineering Aspects

1. Design parameters have been developed and tested for a conventional single-bed ion exchange process with downflow regeneration to remove nitrate from well waters. Testing was conducted using both laboratory columns and a 50.8-cm (20-in.) diameter pilot column.

2. The study indicates that automatic ion exchange equipment, which is commonly used by the water softening industry, can be adapted for nitrate removal. The equipment can be installed at a well site for direct treatment of well water and operated on demand without storage.

3. The selected resin was effective for nitrate removal at loading rates above 48.9 m/h (20 gpm/ft^2) of bed area (1.38 bed volumes/min). This rate was the upper limit of the test equipment used. Such high flow rates bring costs for equipment and resin quantities to low practical levels.

4. Capital equipment costs for an ion exchange system to treat half of a 3,800 m^3/day (1-mgd) production well are estimated to be less than $90,000 installed. This estimate is based on moderate nitrate-nitrogen levels of less than 14 mg/L in well water, sulfate levels of less than 200 mg/L, and blending of treated and raw water to produce a product containing less than 10 mg/L nitrate-nitrogen.

The corresponding equipment cost estimate for a system to treat all water from a 1-mgd production well is less than $150,000. This figure is based on high nitrate levels in raw water (about 23 mg/L as nitrate-nitrogen), high sulfate levels (about 300 mg/L, and ion exchange treatment to reduce nitrate-nitrogen to less than 10 mg/L without blending.

5. A significant operating cost for the process is the cost of sodium chloride used as a resin regenerant. A method is presented to estimate the sodium chloride requirements for regenerating the resin used in nitrate removal from waters of various compositions. Because anion exchange resins are quite selective for sulfate ion, the presence of sulfate in raw water decreases the efficiency of the resin in absorbing nitrate. In this study, however, sulfate was easily removed from the spent resin by the sodium chloride regenerant in nearly stoichiometric proportions, whereas excess regenerant is required for nitrate removal. Nonetheless, the overall effect of sulfate is to increase the salt required to remove nitrate per unit quantity of water treated. This study also confirmed that large quantities of regenerant (320 kg/m^3 or 20 lb/ft^3 of resin) are required to remove most of the nitrate from the spent resin. Not all nitrate need be removed, however, to reduce nitrate-nitrogen levels in treated water to less than 10 mg/L.

For the McFarland wells, the salt costs for lowering nitrate-nitrogen levels to 7 to 10 mg/L ranges from an estimated 1.9¢/1,000 gal of blended water (or $6.10/acre-ft) for well No. 2 to 10¢/1,000 gal of treated water (or $32.50/acre-ft) for well No. 3. Water from the latter well represents a particularly difficult water to treat as nitrate-nitrogen concentrations are near 23 mg/L, and sulfate levels are above 300 mg/L. Nitrate-nitrogen concentrations in well No. 2 are near 14 mg/L, and sulfate levels are near 200 mg/L. Salt requirements for waters of other compositions are given in the report text.

6. To achieve efficient nitrate removal, good brine and influent flow distribution are essential and may require modifications of commercially available softening equipment. A method of declassification (thorough mixing) of the resin after downflow regeneration should also be incorporated in the regeneration cycle.

7. During the regeneration cycle, wastewater is produced that is rich in sodium sulfate, chloride, and nitrate. Continuous operation of well No. 2 would produce more than 45.4 m^3 (12,000 gal) of wastewater/day. Continuous operation of well No. 3 would produce an average of 146.4 m^3 (38,686 gal) of wastewater/day.

Theoretical Aspects

1. Previous studies have shown that the higher resin selectivity for sulfate over nitrate gives rise to some chromatographic sulfate enrichment in the upper portion of spent columns and nitrate enrichment in the lower portion. In studies using McFarland well No. 3 water, such chromatographic separation was observed only for microporous Type I resins. Microporous Type II and macroporous resins appeared to have nearly equal nitrate and sulfate selectivities. The difference in behavior can be attributed to the greater porosity of microporous Type I resins and/or the lesser steric requirements of the Type I resins. This effect has practical significance because it indicates that nitrate selectivity might be increased over sulfate selectivity by decreasing porosity and modifying the structure about the quaternary ammonium ion. To

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

be of practical use, resin selectivity for nitrate must be made to exceed that for sulfate to reverse the order of the enriched portions of the spent resin column.

2. Although ion exchange can be used with minimal salt requirements for some waters, the use of sodium chloride as a regenerant is an obvious disadvantage for extensively employing the conventional single-bed ion exchange process because of waste disposal requirements. Spent brine can be separated into sulfate-rich and nitrate-rich fractions for recovery purposes, but little effort has been spent on developing recovery processes or on using alternative regenerants that could make recovery or reuse more practical.

Recommendations

1. Pilot column studies should be extended and conducted on waters of various compositions to verify the method of estimating engineering design parameters and process requirements. These studies should include Type II resins because of their greater capacity and potential for upflow regeneration.

2. Efforts should be made to reduce regenerant requirements to the lowest level practicable. Such reduction can be achieved by recycling portions of brine and brine rinse as well as backwash waters. Upflow regeneration should also be studied as a method to achieve a low nitrate leakage into the column effluent. This method would make all treated water blendable with raw water and could reduce salt requirements per unit of water produced. The use of RO in conjunction with ion exchange is another approach to reducing regenerant requirements. RO can reduce the total dissolved solids (TDS) load on the resin and may in some cases provide a brine useful for resin regeneration.

3. A demonstration plant of 1,900- to 3,800-m^3/day (0.5- to 1-mgd) capacity should be installed and operated to obtain actual operational experience regarding reliability, health, safety, and costs.

Although the ion exchange process has been used for many years for industrial applications and for removing hardness from domestic supplies, no significant operating experience has been obtained on a full-scale domestic system for nitrate removal. Use of the process for this purpose cannot be considered as a standard engineering application until the process has been successfully demonstrated on a full scale.

4. Efforts to synthesize nitrate-selective resins should be continued to make the process more attractive to sulfate-laden waters. In such studies, close attention must be paid to the regeneration requirements of the new resins.

This interim report is the seventh of a series of quarterly progress reports in fulfillment of a contract under Environmental Protection Agency Grant R-805900-01 to the McFarland Mutual Water Company of McFarland, California. The reader should be aware that ion exchange experiments are being continued under this program and could alter conclusions concerning cost of the ion exchange process reported herein.

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The complete report, entitled "Removal of Nitrate from Contaminated Water Supplies for Public Use," (Order No. PB 163 206; Cost: $11.00, subject to change) will be available only from:
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U.S. Environmental Protection Agency
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• U.S. GOVERNMENT PRINTING OFFICE: 1981-757-012/7074

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